LCA Case Studies

Wastepaper in Mumbai (India)

An Approach for Abridged Life Cycle Assessment

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Abstract. In this study, the Life Cycle Assessment (LCA) of wastepaper was conducted in Mumbai (India). The wastepaper cycle was divided into four main life stages – Generation, Collection, Utilisation and Disposal. A survey of major stakeholders involved in this cycle, namely informal waste-pickers, buyers, wholesalers and paper manufacturers, was carried out to determine the socio-economic and environmental aspect of each stage. The LCA Abridged Matrix Method was applied for Life Cycle Assessment. The resulting LCA matrix showed that, while there was a moderate environmental impact of wastepaper during generation, collection and disposal stages, the utilisation stage had a significant impact on the environment, especially during manufacturing in paper factories.

Keywords: CBA; Cost Benefit Analysis (CBA); disposal of wastepaper; EIA; Environmental Impact Assessment (EIA); environmental impact of wastepaper; India; LCA abridged matrix method; LCA; Life Cycle Assessment; Mumbai; municipal solid waste (MSW) in India; socio-economic aspect of wastepaper; wastepaper

Introduction

Determining the overall environmental soundness of a product or process is far from a simple matter. There are many criteria by which the product has to be judged. The result depends on the relative importance of these criteria. Some of the main tools for the assessment of environmental consequences in practice are – Cost Benefit Analysis (CBA), Environmental Impact Assessment (EIA), with the latest being Life Cycle Assessment (LCA).

Life Cycle Assessment, as the name implies, is an apparently straightforward methodology for assessing all the environmental impacts of a product, process or service, from 'cradle to grave', i.e. from initial extraction of raw materials to their final disposal. LCA quantifies the environmental impacts of a product or material over its entire life span, which includes the extraction of raw materials, their processing, manufacturing and fabrication of the product, transportation and distribution of the product to consumers; the use of the product by the consumer; and the disposal and/or recovery of the product after its useful life [1].

In this article, wastepaper has been selected for the abridged LCA in Mumbai, India because it plays an important role on environmental and socio-economic fronts in the society. The average paper content of municipal solid waste (MSW) in India is around 5-6%, which is in sharp contrast to the world average of about 30% by weight [2]. Due to this difference of MSW composition, the overall environmental impacts of wastepaper are bound to be different in India. Furthermore, there is a huge network of people involved in informal waste collection in India, which has appreciable socio-economic implications. In this article, an attempt has been made to assess some of the major environmental and socio-economic impacts of wastepaper through a case study conducted in the metropolitan city of Mumbai, India.

1 Wastepaper Cycle

Broadly, the wastepaper lifecycle can be divided into four main stages, namely, Generation, Collection, Utilisation and Disposal as discussed below.

Generation: The first stage in the life cycle of wastepaper is the generation of wastepaper. The generation is mostly from three sectors- household, industrial and commercial. The industrial and commercial sectors include government departments, private companies and shops.

Collection: The collection of wastepaper in India mostly takes place in urban centres. The main stakeholders informally involved in the collection of wastepaper are Waste-pickers, Itinerant Waste Buyers (IWB), Buyers and Wholesalers.

Waste-pickers contribute a lot to the solid waste management in urban regions of India. The waste-pickers, are mostly unskilled migrants from villages who roam the city streets and waste dumpsites to collect the recyclable material such as wastepaper, plastics, glass and metals, which they can sell to the buyers. The wastepaper collected by them is "mixed" and carries less of a market value. The IWB form a major part of collection of wastepaper in Indian cities. They go door-to-door, around the city, on bicycles or even on foot and collect the wastepaper. The IWB are important for wastepaper cycle as they obtain segregated waste at source before it is mixed, damaged or contaminated [3,4]

The buyers are intermediaries who buy waste either from the waste-pickers, IWB or directly from households and sell it to the wholesalers. The buyers operate from a fixed location, and generally prefer residential areas probably for minimising the distance to the suppliers. Buyers deal in every type of recyclable material including wastepaper.

The wholesalers distinguish themselves by trading in one type of waste, operating on a larger scale than buyers and supplying directly to paper mills. The most important suppliers of waste to the wholesalers are waste-pickers, IWB, buyers, commercial establishments and households. Dealers of sorted paper such as newspapers, magazines, etc. have a higher ranking than those dealing with the "mixed paper" i.e. a mixture of paper, board, etc. that has been retrieved from the garbage bins [4,5].

Utilisation: The wastepaper through the collection stage reaches the paper factory where it is used with other raw materials to produce paper. In India, the wastepaper is reused in the form of loose packaging for various grocery items. Although the trend of using paper in such packages has been reduced due to health and environmental concerns, a substantial quantity is still being used. However, it is very difficult to estimate the quantity of paper used in this activity and it is kept out of the scope of this paper.

Paper factories are the major players in the utilisation stage. The main raw materials used in the Indian paper industry are wood-based pulp, agro-based pulp and wastepaper. The other inputs being power, water, chemicals and colourants like alum, rosin, talc, etc. Factories produce paper of various grades and some by-products are released during the process. Environmental problems like air emissions, wastewater and solid waste are among these by-products.

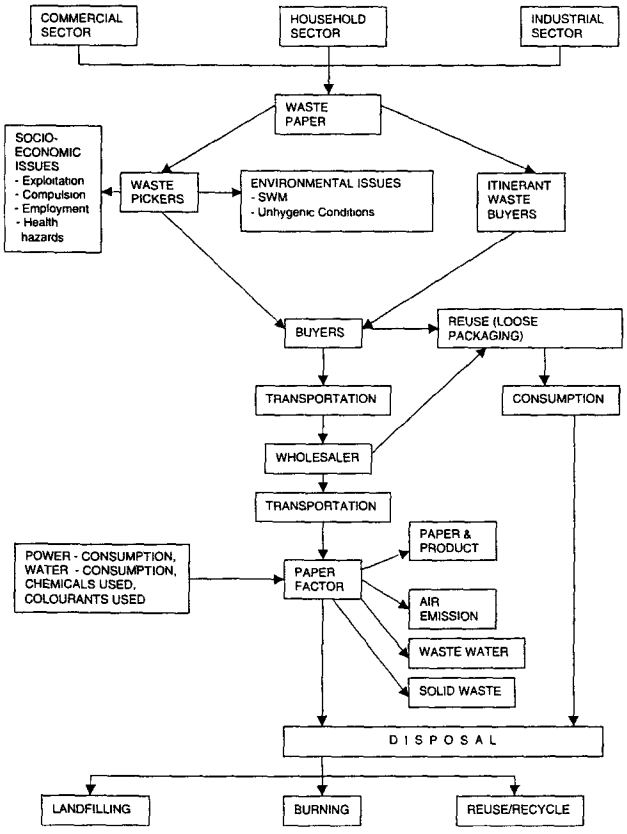

Fig. 1: Wastepaper cycle in India

A part of the utilisation also involves reuse of wastepaper without reprocessing taking place. Reuse has a negative effect on the quality of the wastepaper and it is assumed that paper that is reused can no longer be available for recycling. This implies that the quantity of unrecoverable wastepaper for disposal will increase if more wastepaper is reused.

Disposal: The two main methods for the disposal of wastepaper are Incineration and Landfilling. The wastepaper can be incinerated or burned in order to reduce the volume of solid waste, but this process creates considerable air pollution. Instead of burning wastepaper, it can be mixed with the household waste. It then ends up at the dumpsite of land filling site where it decomposes into organic matter.

The detailed wastepaper cycle as prevalent in India is shown in Fig. 1.

2 Status of LCA in India

LCA is a study area that is undergoing rapid advances and change. The work of standardisation of LCA has recently been initiated in India. To further the cause of sustainable development, "Indian Society for Life Cycle Assessment (ISLCA)" was established on December 13, 1997 by the "National Ecology and Environment Foundation (NEEF)" on the lines of Life Cycle Assessment Society of Japan (JLCA). The main objectives of ISLCA are [6-9]:

- To build Innovative Environmental Consciousness in India,
- To provide environmental knowledge,
- To create, develop and deploy new knowledge in environmental principle and practices,
- To provide leadership for ecobalance,
- To integrate sociological issues for LCA,
- To develop LCA framework and
- To facilitate innovative environmental culture in organisations.

2.1 Current stage of LCA development

The LCA exercise in India has just begun. To date, the Government requirement is limited to Cost-Benefit Analysis (CBA) and Environmental Impact Assessment (EIA) Exercises. To be more specific, under various headings, the LCA status in India can be described as follows:

a)	Country Level of Government support:	Poor
b)	Level of Industry support:	Poor
c)	Level of Academic activity:	Fair
d)	Methodology development:	Poor
d)	Inventory data development:	Fair
e)	Public availability of data:	Fair
f)	Impact Assessment development:	Good

3 Data Collection and Analysis

The data collection for the study was carried out with the help of an interview-cum-questionnaire method. The target population for the study included waste-pickers, buyers, wholesalers and paper manufacturers – all playing a major

role in the wastepaper cycle of India. A total of 40 informal waste-pickers who collect wastepaper and other recyclable material from the street, dumpsites, garbage bins, etc. were selected randomly. In addition, 20 buyers whom waste-pickers approach for selling of their collected material and 10 wholesalers who purchase wastepaper from the buyers and others and sell it to the factories were included in the study. The data was also collected from seven paper factories situated around Mumbai. The data obtained was analysed for LCA using the Abridged Matrix Approach.

3.1 Use of matrix approach for LCA

It is difficult to deal with the lengthy and complex procedures for life cycle assessment and, at the same time, to produce an improvement in analysis which can be useful to decision-makers [10]. Theoretically, LCA can be a never-ending process. To make it most effective, it must be conducted in a modest depth. As a result, abridged assessment protocols are being developed using the matrix approach to LCA. One of such protocols has been discussed in detail by Graedel et al. (1995) using the example of environmental impacts of automobiles [11]. On similar lines, this study has attempted to perform LCA of wastepaper in India and also included the social impact along with the environmental impact of the wastepaper cycle.

Accordingly, the four stages of wastepaper cycle stated above, i.e. generation, collection, utilisation and disposal, can be sub-divided into 8 stages having 9 types of environmental and social concerns, as shown in Table 1. Thus, the assessment system has an 8×9 matrix. On the basis of the survey carried out, each element of the matrix is assigned an integer rating from 0 (highest impact, a very negative evaluation) to 4 (lowest impact, an exemplary evaluation). Here, assessing the integer ratings is being performed with the help of literature, experience from the field survey and other information available (→ *Table 2, p. 15*).

Once an evaluation has been made for each matrix element, the overall Environmentally and Socially Responsible Product Rating (R_{ESRP}) is computed as a sum of the matrix element values.

$$R_{ESRP} = \Sigma i\, \Sigma j\, Mij$$
$$= 8 \times 9$$
$$= 72$$

Since there are 72 matrix elements, a maximum product rating is 288 (72×4).

4 Results and Discussion

Table 2 has been constructed by keeping in view a 0-4 ranking of various environmental and social impacts of wastepaper during its different life stages. All the elements are shown in the table and their brief explanation is given. Some important points are further explained as below.

1) The first life cycle stage, i.e. **generation**, has the least impact on environment and social aspects. This is because the wastepaper is mainly generated in household, industrial and commercial sectors, which mostly take care of their waste for economic reasons and cause negligible impacts. The only environmental impact can be the generation of solid waste in the form of wastepaper, if it is not utilised or disposed of properly, i.e. litter.
2) The **collection stage** has been further sub-divided into collection by waste-pickers, buyers and wholesalers. These three stakeholders help as a pathway for the collection of the wastepaper from its point of generation to the next stage of the wastepaper cycle, i.e. utilisation either by paper factories or for reuse by establishments like retail shops, etc. Waste-pickers contribute towards creating a positive environmental impact as they help in reducing the solid waste. In case of buyers, the transport emissions are generated causing negative environmental impact to a certain extent as wastepaper is transported to wholesalers within the same city. And in case of wholesalers, the environmental impact is due to transportation of wastepaper from their storage to paper factories. This is because most of the paper factories are situated outside Mumbai in towns like Vapi, Nasik, Jalgoan etc. Thus, in the case of wholesalers, the distance travelled is greater than by buyers, so the emissions due to transportation are also greater to the environment.

Table 1: Environmentally and socially responsible product assessment matrix (the numbers in each box are the matrix element indices)

Life Cycle Stage	Environmental and Social Concern								
	Raw materials	Energy consumption	Water consumption	Air emissions	Solid waste	Waste water	Social problems	Health problems	Employment
Generation	(1,1)	(1,2)	(1,3)	(1,4)	(1,5)	(1,6)	(1,7)	(1,8)	(1,9)
Collection									
- Wastepickers	(2,1)	(2,2)	(2,3)	(2,4)	(2,5)	(2,6)	(2,7)	(2,8)	(2,9)
- Buyers	(3,1)	(3,2)	(3,3)	(3,4)	(3,5)	(3,6)	(3,7)	(3,8)	(3,9)
_ Wholesalers	(4,1)	(4,2)	(4,3)	(4,4)	(4,5)	(4,6)	(4,7)	(4,8)	(4,9)
Utilisation									
- Factories/ recycling	(5,1)	(5,2)	(5,3)	(5,4)	(5,5)	(5,6)	(5,7)	(5,8)	(5,9)
- Reuse	(6,1)	(6,2)	(6,3)	(6,4)	(6,5)	(6,6)	(6,7)	(6,8)	(6,9)
Disposal									
- Landfilling	(7,1)	(7,2)	(7,3)	(7,4)	(7,5)	(7,6)	(7,7)	(7,8)	(7,9)
- Incineration	(8,1)	(8,2)	(8,3)	(8,4)	(8,5)	(8,6)	(8,7)	(8,8)	(8,9)

Table 2: Environmentally and socially responsible product assessment ratings (explanation by Life Cycle Stage)

Element Design	Matrix Element Indices[a]	Elemental Value[b]	Explanation
Generation			
Raw materials	(1,1)	4	No raw materials used
Energy consumption	(1,2)	4	No energy consumed
Water consumption	(1,3)	4	No water consumption
Air emissions	(1,4)	4	No air and transport emissions
Solid waste	(1,5)	2	Solid waste is produced as waste paper
Waste water	(1,6)	4	No waste water produced
Social problems	(1,7)	4	No social problems
Health problems	(1,8)	4	No health problems
Employment	(1,9)	4	No effect on employment
Collection			
i) wastepickers			
Raw materials	(2,1)	4	No raw materials used
Energy consumption	(2,2)	4	No energy consumption
Water consumption	(2,3)	4	No water consumption
Air emssions	(2,4)	4	No air emissions
Solid waste	(2,5)	3	Solid waste as wastepaper is collected by the wastepickers
Waste water	(2,6)	4	No waste water produced
Social problems	(2,7)	3	Some exploitation of wastepickers
Health hazards	(2,8)	2	Some wastepickers have health problems
Employment	(2,9)	3	Wastepickers otherwise unemployed get self-employment
ii) buyers			
Raw materials	(3,1)	4	No raw materials used
Energy consumption	(3,2)	4	No energy consumption
Water consumption	(3,3)	4	No water consumption
Air emissions	(3,4)	2	Air emissions due to transportation when wastepaper is transported to wholesalers within the city
Solid waste	(3,5)	3	Solid waste in the form of wastepaper is collected
Waste water	(3,6)	4	No waste water is produced
Social problems	(3,7)	4	No social problem
Health problems	(3,8)	3	As working with waste paper has some health problems
Employment	(3,9)	2	Buyers generate employment
iii) wholesalers			
Raw materials	(4,1)	4	No raw materials used
Energy consumption	(4,2)	4	No energy consumed
Water consumption	(4,3)	4	No water consumption
Air emissions	(4,4)	1	More air emissions due to transportation to paper factories outside Mumbai
Solid waste	(4,5)	3	Solid waste is reduced when waste paper is sent to factories for recycling
Waste water	(4,6)	4	No waste water produced
Social problems	(4,7)	3	Solid waste is reduced
Health problems	(4,8)	4	No health problems
Employment	(4,9)	2	Wholesalers employ workers
Utilisation			
i) recycling by mills			
Raw materials	(5,1)	2	Raw materials are used in the manufacture of paper
Energy consumption	(5,2)	1	Energy intensive process
Water consumption	(5,3)	1	Water intensive process
Air emissions	(5,4)	1	Lot of air emissions from process, stack and transportation within the paper factories
Solid waste	(5,5)	1	Solid waste as output is produced

Table 2 (*cont'd*): Environmentally and socially responsible product assessment ratings (explanation by Life Cycle Stage)

Element Design	Matrix Element Indices[a]	Elemental Value[b]	Explanation
Waste water	(5,6)	0	A large amount of BOD & COD are discharged in the waste water
Social problems	(5,7)	4	No social problems are there
Health problems	(5,8)	0	Air emissions are dangerous to health of workers and residents around factories
Employment	(5,9)	3	Many people get employment in paper factories
ii) reuse			
Raw materials	(6,1)	4	No raw materials used
Energy consumption	(6,2)	4	No energy consumed
Water consumption	(6,3)	4	No water consumed
Air emissions	(6,4)	2	Air emissions due to transportation when wastepaper is transported to shopkeepers
Solid waste	(6,5)	1	Solid waste increases due to reuse of wastepaper
Waste water	(6,6)	4	No waste water produced
Social problems	(6,7)	3	No social problems
Health problems	(6,8)	1	Chemicals & ink of waste paper used for loose packaging contaminates edibles
Employment	(6,9)	3	People are employed by shopkeepers to manufacture paper bags
Disposal			
i) Landfilling			
Raw materials	(7,1)	4	No raw materials used
Energy consumption	(7,2)	4	No energy consumed
Water consumption	(7,3)	4	No water consumption
Air emissions	(7,4)	2	Air emissions generated as wastepaper transported from generation point to landfilling ground
Solid waste	(7,5)	1	Lot of solid waste to tackle
Waste water	(7,6)	4	No waste water produced
Social problems	(7,7)	3	Some social problems of unsightly landfill sites
Health problems	(7,8)	2	People residing near landfilling grounds can have some health problems
Employment	(7,9)	3	Some effect on employment
ii) incineration			
Raw materials	(8,1)	4	No raw materials used
Energy consumption	(8,2)	2	Energy is consumed while incinerating wastepaper
Water consumption	(8,3)	4	No water consumed
Air emissions	(8,4)	0	Lot of air emissions due to transportation and incineration of waste paper
Solid waste	(8,5)	4	Negligible solid waste is produced
Waste water	(8,6)	4	No waste water is produced
Social problems	(8,7)	3	No social problems
Health problems	(8,8)	1	Due to air emissions workers in the incinerating plant can have respiratory problems
Employment	(8,9)	3	Some effect on employment

a shown in the Figure
b Matrix elements are assigned an integer ranging from 0 (highest impact) to 4 (lowest impact)

3) **Utilisation** deals with the two aspects, a) recycling by paper factories and b) reuse of paper for loose packaging. In paper factories, wastepaper plays a significantly positive role as a substitute for virgin materials (wood, agro-products, etc.) which are becoming scarce day by day. The main negative environmental concern here is the wastewater released during the manufacturing process of paper containing a high Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). This wastewater is released into water streams, like rivers, lakes, oceans, etc., and thus poses danger to marine life as well as polluting the sources of water supply. The air emissions and solid wastes generated are also of much concern. The air emissions are hazardous for the health of workers in paper factories. In case of reuse, firstly, the quality of wastepaper deteriorates and it can not be used

again for making paper and thus has to be either land filled or incinerated and, secondly, it adds to the volume of solid waste. The transportation of wastepaper from buyers and wholesalers to the point of reuse (shops, etc.) emits pollutants which again have some negative effect on the environment. The reuse of paper is also dangerous for human health, because when newspaper, magazines etc. are used for packaging of food and other edible items, the newsprint or the ink particles may penetrate into the food articles which are consequently ingested.

4) As mentioned earlier, the **disposal** of wastepaper involves either landfilling or incineration. In the case of landfilling, the air emissions are released due to transportation of wastepaper from the point of utilisation to a suitable landfill site. The wastepaper also adds to the solid waste. Due to the incineration of wastepaper, the air emissions are very high containing smoke and many hazardous gases. Also, the transportation from the point of generation to place of incineration will produce transport emissions.

In view of the above, the rating (0 to 4) for various elements of matrix has been assigned and the completed matrix for the wastepaper cycle has been illustrated in **Table 3**. The numbers in the 'total' column show a moderate environmental stewardship during generation. The ratings for the utilisation stage by factories are poor and the rest, during collection, utilisation and disposal by reuse, is moderate.

As shown in Table 3, the overall rating comes out to be 214, while the total for each row is 36 and that for each column is 32. As there are 9 columns and the largest integer is 4, the total of each row turns out to be 36 (9×4), in the same way there are 9 rows with the largest integer being 4 so that the total for each column is 32 (8×4). Because there are 72 matrix elements (8×9) and the total of each row and column is 36 and 32, respectively, the maximum product rating will be 288 (36×8 or 32×9) as depicted in the table.

The matrix provides a useful overall assessment of wastepaper but a more concise display of the assessment is provided by the 'target plots' shown in **Fig. 2** (→ *p. 18*). To construct the target plots, the matrix is plotted at a specific angle (for a 72 element matrix, the angle spacing is 360/72 = 5°). An environmentally sound product shows up as a series of dots bunched at the centre, as would occur on a rifle target in which each shot was aimed accurately. The same is seen in the target plots drawn for the wastepaper. Since the target plots here considered both environmental and social aspects, it can be assessed that the environmental and social impacts of wastepaper are not very significant.

5 Conclusions

The life cycle concept is very important to study any product, process or activity, and in order to assess its environmental suitability. The environmental and social impacts of the wastepaper cycle were assessed using an abridged matrix approach for LCA. The field survey of informal wastepickers shows that although they contribute a lot to solid waste management in India, they are in a very poor state. The data collected was used to form the matrices and for drawing the target plots. The diagram shows that the overall impact of the wastepaper on the environment and society is not very high. Although the LCA approach presented here is not very quantifiable and thorough, it suggests that it is better to conduct a number of abridged LCAs by these or similar techniques than to conduct one or two comprehensive LCAs which may take a much longer time. Such LCAs will also help in recommending solutions to decrease the environmental and social impacts at every life cycle stage of a particular product, process or activity.

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Table 3: Environmentally and socially responsible product assessments

Life Cycle Stage	Environmental and Social Concern									Total
	Raw materials	Energy consumption	Water consumption	Air emissions	Solid waste	Waste water	Social problems	Health problems	Employment	
Generation	4	4	4	4	2	4	4	3	4	33/36
Collection										
- Wastepickers	4	4	4	4	3	4	3	2	3	31/36
- Buyers	4	4	4	2	3	4	4	3	2	30/36
- Wholesalers	4	4	4	1	3	4	3	4	2	29/36
Utilisation										
- Factories/ Recycling	2	1	1	1	1	0	4	0	3	13/36
- Reuse	4	4	4	2	1	4	3	1	3	26/36
Disposal										
- Landfiling	4	4	4	2	1	4	3	2	3	27/36
- Incineration	4	2	4	0	4	4	3	1	3	25/36
Total	30/32	27/32	29/32	16/32	18/32	28/32	27/32	16/32	23/32	214 228

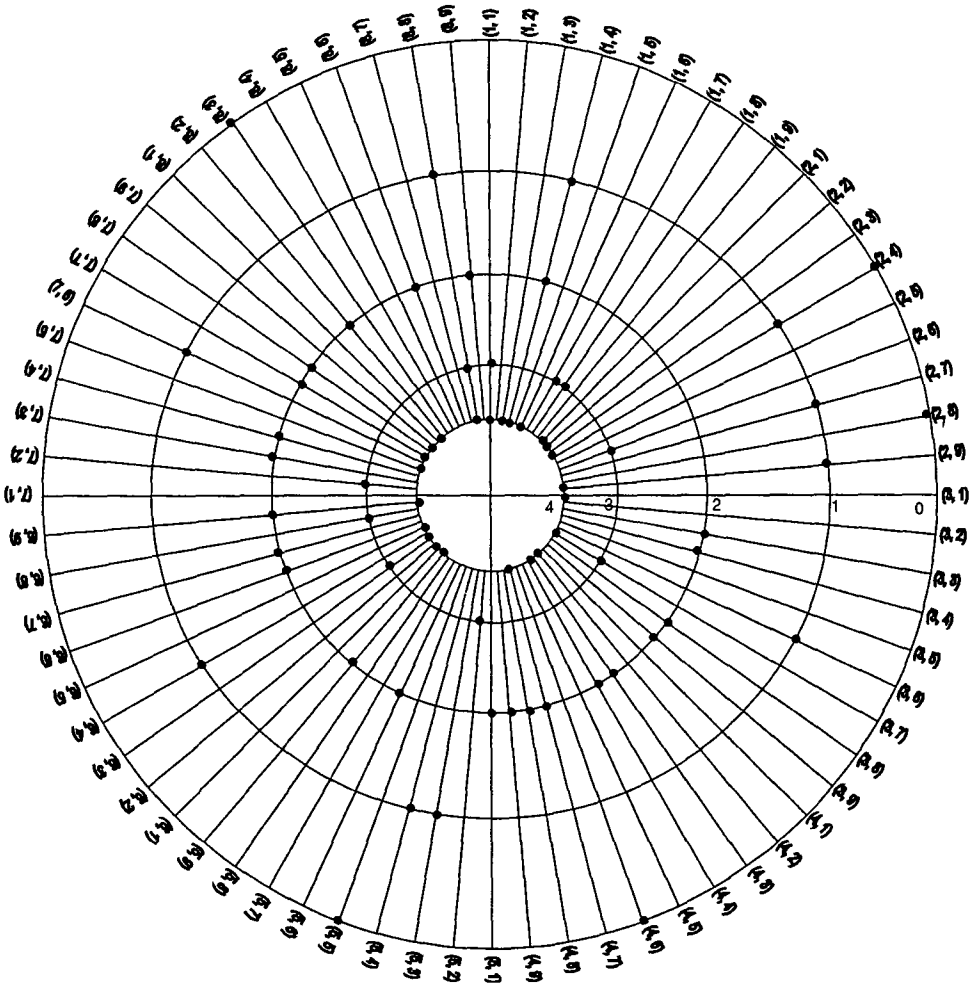

Fig. 2: Target plots for wastepaper cycle

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